Retrieval Of Soil Moisture Content From Naturally Vegetated Upland Areas Using ERS-1/2 Synthetic Aperture Radar

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Abstract

A novel algorithm has been used to derive soil moisture content from SAR imagery. Based upon a simplified Kirchhoff scattering model, the algorithm separates the contribution to the backscatter into that from the soil and that due to the surface roughness and slope effects. It is designed not to require intense ground calibration.

The method has been tested over a naturally vegetated hillside in the West Pennine Moors in Lancashire, England where a field site has been established. Comparative measurements have been made using a capacitance probe and a weighing lysimeter. The algorithm produces good estimates of soil moisture from SAR data when compared to rootzone measurements made with the capacitance probe, thereby showing the potential for SAR in this field.

Comparisons with the column soil moisture content measured by the lysimeter show the limitations of remotely sensed soil moisture when moisture is present only at depth. This is most important in the derivation of evapotranspiration rates and surface heat fluxes using remotely sensed soil moisture values.

Keywords: SAR, soil moisture, evapotranspiration.

Introduction

The observation of soil moisture content (SMC) over wide areas is crucial to the understanding and modelling of boundary layer convection, as well as aiding the distribution of irrigated supplies of water for agricultural usage. The availability of moisture for evapotranspiration (ET) is a critical parameter in the partition of energy at the Earth s surface and the quantity of water entering the atmosphere will regulate cloud formation and precipitation. If SMC could be monitored accurately on a regular basis then ET can be deduced.

There are a number of methods of observing SMC currently used, many of these (eg. neutron probes, Penman Monteith methods) use point measurements at the surface which then have to be extrapolated to give an areal estimate. L-band passive microwave observations have been shown to be effective (Njoku and Entekhabi, 1996) but will suffer when the canopy height is large or if there is cloud cover.

The problem of cloud cover is solved by using an active device such as the SAR. Concern has been expressed as to the effectiveness of a method involving SAR data to retrieve SMC from naturally vegetated and hilly areas and experimental work has therefore concentrated on flat, homogeneously vegetated or bare soil areas (Ulaby *et al,* 1996).

Experiment

The study described here was part of a larger program concerned with the prediction of potential flood events in data sparse areas (Saich *et al.,* 1997). A section of the project deals with the derivation of a SMC measuring tool using SAR data. To this end a physically based model of the surface scattering was used to divide the radar backscatter into components due to the surface roughness and the soil dielectric properties. This is detailed in Saich *et al.* in this volume.

The radar backscatter ($_{dB}$) is related to the Fresnel reflection coefficient (R) by the equation

$$_{dB} = A + 20 \log_{10R} \tag{1}$$

A is a constant that could be determined by numerical simulation of the surface scattering characteristics but in this case was empirically found by fitting to the ground truth data. The SMC is retrieved from the value of R by its relationship to the permittivity (Saich *et al.,* 1997). This method implies the need for some ground measurements to initialise the value of A if one is to achieve an absolute measure of SMC.

Comparisons were made between the six values of SMC derived from the SAR data through the summer of 1996 and *in situ* measurements. These latter were made with a theta-probe (manufactured by Delta-T Instruments, Cambridge, UK) and a weighing lysimeter (constructed at the Institute of Terrestrial Ecology, Merlewood, UK). The theta-probe is a time domain reflectometry (TDR) device and was installed for the entire measuring period. It was buried at a depth of between 5cm and 10cm and therefore is sensitive to the SMC within the root-zone. The weighing lysimeter contained an undisturbed soil column of diameter 31cm and length 37cm topped by natural grass. It was installed on July 12th 1996.

The test site for the experiment is located at Haslingden Grane in Lancashire, Northwest England. The area is part of the West Pennine Moors and as such has some steep slopes. The vegetation is mainly long, growing grass but there are stands of trees in the vicinity, as well as reservoir surface and hill tops with some bare rock outcrops. The grass was of the order of 10cm in length at the time of the initial observations in May, increasing to up to 30cm by September.

Results

Six measurements of SMC found from the SAR imagery of the single 100m pixel containing the field site are compared to the ground measurements shown in figure 1. A seventh image acquired from an ascending pass showed distinct characteristics from the six descending passes and is not shown. The spikes in the theta-probe record are artifacts created when the power supply is renewed.

It is apparent that there exists considerable correspondence between the values of SMC found from the SAR data and that from the theta-probe, however there are insufficient data to determine the reliability of the technique. It is evident that the SAR discriminates between the wetter conditions earlier in the period from the dry conditions around day 240. The agreement with the theta-probe is perhaps to be expected as both instruments should respond similarly to the dielectric constant of the top few centimetres of soil. As the soil column retains water at its base for longer and fills up more quickly after rainfall it can be seen that the column SMC as measured by the lysimeter is not well represented by the SAR estimates.

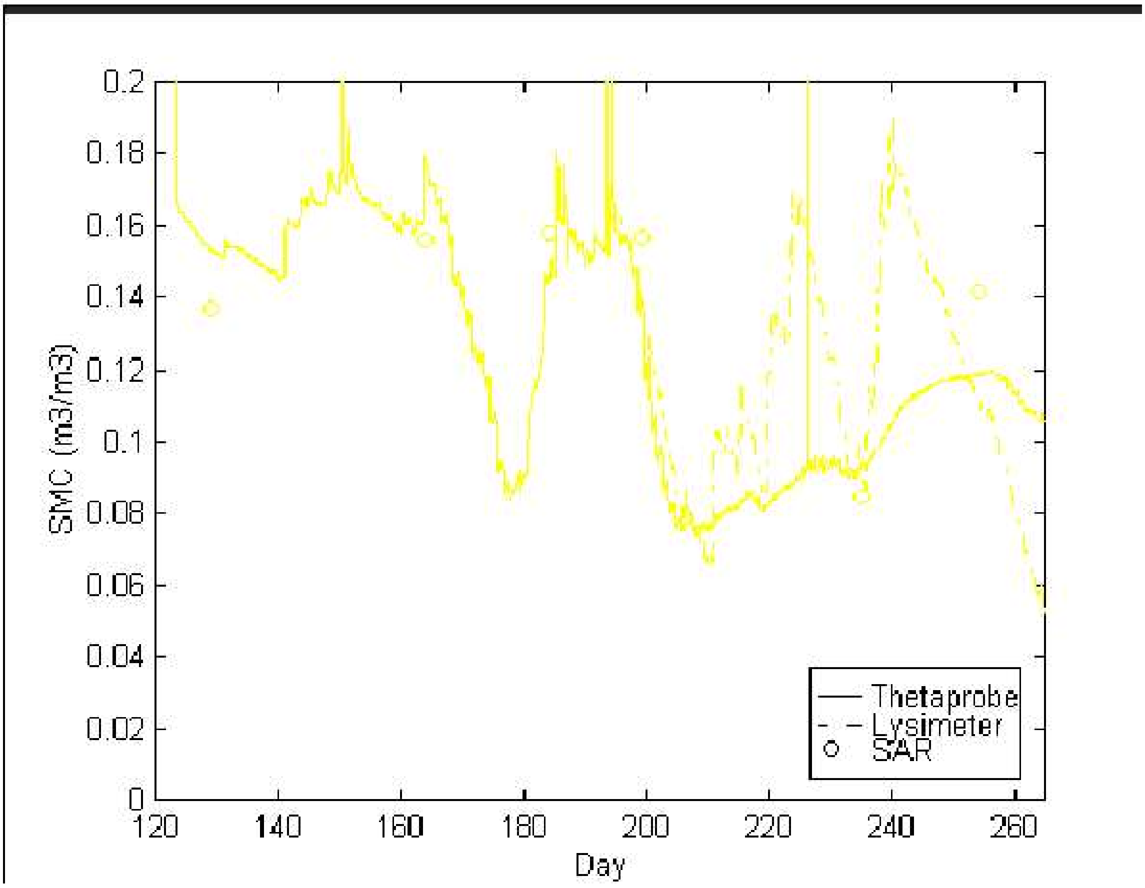

Figure 1: Comparison of SAR derived soil moisture with that measured by the thetaprobe and the lysimeter.

Evapotranspiration

If one assumes that the SAR will measure the surface layer SMC in a similar way to the theta-probe then one can use the probe measurements to simulate ET values that could be derived from remotely sensed SMC. (It is perhaps worth noting that passive microwave methods would show similar behaviour). Such areal ET measurements are important in assessing the surface energy budget and would be of great benefit to climate modelers and boundary layer meteorologists.

In the area of Northwest England over which this study took place the SAR has a return period of 35 days so that an application such as the one being discussed is not practical. However a theoretical instrument which makes a daily pass would still have the limitations detailed in this section.

By adding the component of the water balance due to rainfall measured at the field site one can deduce the ET from the differences in the SMC recorded by the theta-probe and the lysimeter. The 2 methods are compared in figure 2.

It is seen that initially, when the lysimeter was installed on day 194, the two instruments produce values of ET that are in excellent agreement. At this stage there is still moisture available in the top layer of the soil. When the hot dry spell continues this surface layer dries out completely and no further ET takes place to deplete the SMC observed with the theta-probe. The lysimeter, on the other hand, continues to show that ET is taking place as water is drawn by deeper roots to the canopy from where it is evaporated.

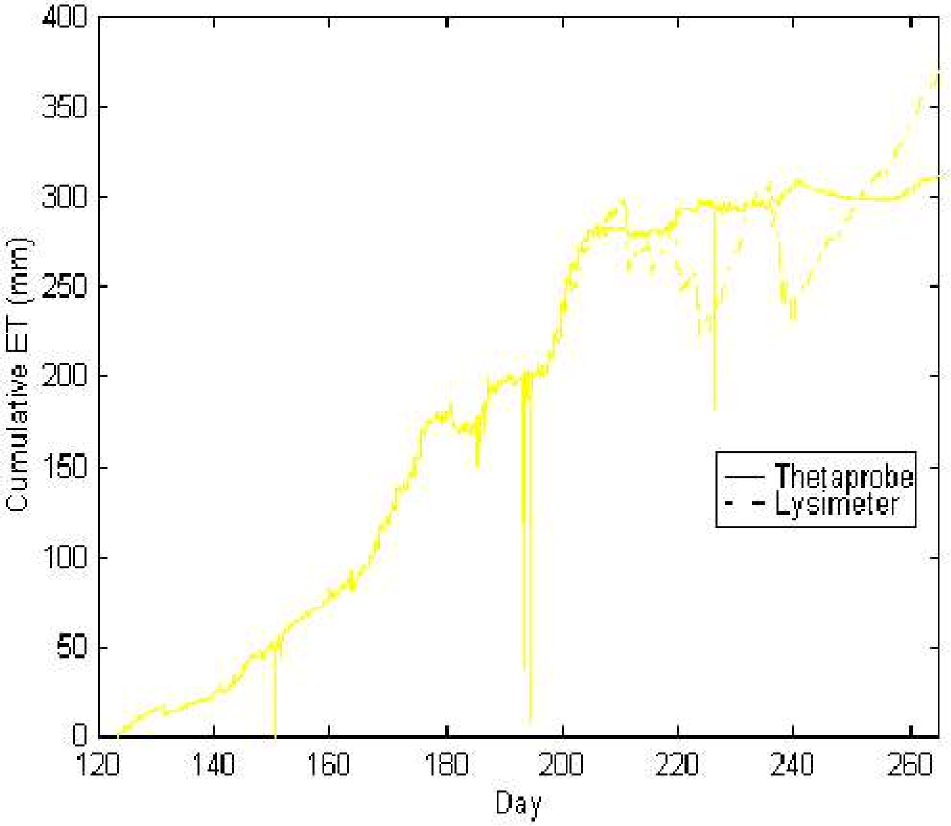

Figure 2: The evapotranspiration found from measurements with the thetaprobe and the lysimeter.

Discussion

It is evident that caution is required if remote sensing methods are to be used for the areal observation of SMC and ET. If one assumes that one can accurately determine the condition of the surface one may still need to make some surface investigation to correctly deduce the moisture available for crop use and ET. For instance, it may be useful to know the total soil depth, type and root penetration.

Once the surface is dry and there is no further change in the remotely sensed SMC one would have to extrapolate the ET by assuming, primarily that water remains deeper in the soil and secondly, that climatological factors remain reasonably constant and one has knowledge of the behaviour of the vegetation with regard to water under such conditions

Conclusions

It has been demonstrated that SAR offers a possible way of monitoring SMC changes and, if calibrated, absolute values in areas of varied, natural vegetation and steep slopes. This is a useful application of SAR as much can be deduced from the surface layer SMC. However, more data is required to complete a detailed assessment of the effectiveness of the technique.

The response of the lysimeter to the column soil moisture content suggests that care must be taken if one wishes to use remotely sensed SMC measurements for boundary layer modelling or agricultural applications.

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References

Njoku and D. Entekhabi, 1996: